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Balcony Typology and Energy performance in Residential Buildings

Elahe Mirabi, Nazanin Nasrollahi

***Abstract*— Buildings and its surrounding environment contribute to producing greenhouse gases associated with more pollution and creation of urban heat island. Residential buildings have a major part in energy consumption, resulting in wasting natural and renewable energy.**

For this reason, optimizing the energy usage for housing is vital. The most critical part of a building is the envelope because it influences the energy consumption due to its exposure to the surrounding environment. Many elements of building facades have considerable thermal performance such as balcony. In the meantime, there are few studies concerning the balcony as an important passive element in modern buildings. Therefore, this paper aims to investigate the significant parameters in forming the optimal design for balcony and suggest the best model with regards to reducing energy consumption. The research process is carried out in three stages: desk research, analysis of prevalent balconies in Tehran, and simulation of different parameters of balcony using Energy Plus software. The simulation results reveal that the best balcony pattern to reduce energy consumption in Tehran is the south-ward, rectangular, west-enclosed, protrusive and with porous partition (vertical dividers). The most influential factor is the balcony type. The simulations show that protrusive balconies could reduce energy consumption up to 60% in comparison to reentrant balconies.

***Index Terms*— Balcony, Energy Consumption, Energy Plus, Energy Performance.**

I. INTRODUCTION

Buildings account for a large portion of the total energy consumption rather than other sectors in many advanced countries [1-3], consuming approximately 40% of total primary energy and producing more than one-third of carbon dioxide emissions [4-6]. This is mainly due to the tendency to use HVAC [7-12] which emit more than 30% of the released carbon dioxide [13, 14]. In regards to the climate change such as global warming, there is a concern about the use of fossil fuels due to the direct relationship between energy consumption and carbon emissions [15]. The aforementioned statement can be justified since the buildings account for almost 70% of the total energy in the world [16]. The energy consumption is mainly due to the HVAC systems.

A large portion of the energy savings can be attained through applying a wide range of temperature fluctuations in the interior spaces [17] through which some studies have been conducted to enhance the energy efficiency of the buildings [18-32], especially using effective design in the external walls of the buildings [33-39]. In addition, the energy consumption reduction of the buildings in different climates on the urban surfaces (intersection between urban canyons and buildings) has gained wide acceptance both in academia and practitioner world [40-45]. This affects the modern design of the building's facades [46,47]; knowing of the passive methods, less cooling loads and thus less energy consumption can be achieved with using no air conditioning [47].

Along with the vertical growth of towns and buildings, the use of the courtyard has been replaced with the modern balconies. In this regard, balconies play the significant role in providing thermal comfort and reducing the energy consumption of the buildings because they have the potential to provide a cover to protect the buildings against the wind and reduce the pressure and suction in most areas of the building's surface by creating pressure fluctuations on the walls [48], subsequently yields in enrichment of air conditioning [49]. Balconies help directing and allowing inflow in order to change the natural ventilation indoors [50-57]. By shadowing the solar radiation and storing electricity, with a transparent glass window, the highest storage percentage of 12.3% in A/C consumption was provided by balconies [58]. Therefore, if the balcony's parameters are properly designed, in addition to better safety of building against wind pressures, it also can simultaneously reduce the energy consumption through providing thermal and ventilation comfort. However, no comprehensive research has been carried out on the effects of balconies properties on energy consumption. In this study, we have tried to examine the effect of different balcony parameters on the energy consumption of the buildings.

II. RESEARCH METHOD

For this study Tehran has been selected, which is coordinated at 35.7117°N & 51.4070°E [59]. The climate in Tehran is warm and dry in summer, with a maximum temperature of 42.6 ° C and is moderate and cold in winter with a minimum temperature of -10 °C. Relative humidity is 41% as an average and with a minimum of 28% and a maximum of 56% [60].

Initially, 1140 buildings are investigated and a basic model will be provided based on the typical buildings in Tehran. In this study, Energy Plus software [61], version 6.2.8 has been utilized for the thermal simulation, calculating cooling and heating loads. Simulation process is as TABLE 1. In order to achieve the optimal typology of balcony, in every step, the most efficient parameter will be selected for the next step. It is worth to note that all the simulated dimensions, sizes and shapes are based on the common balconies and building codes in Tehran.

In order to obtain a base model using field surveys in Tehran, a total of 1140 buildings have been investigated. In this survey, the number of building stories, balcony-contained buildings and balcony parameters like orientation, geometry, type and enclosure have been examined. Fig. 1 shows the results of field studies.

Elahe Mirabi, Department of architecture, Ilam University, Ilam, Iran, 09383476758.

Nazanin Nasrollahi, Department of architecture, Ilam University, Ilam, Iran, 09383476758

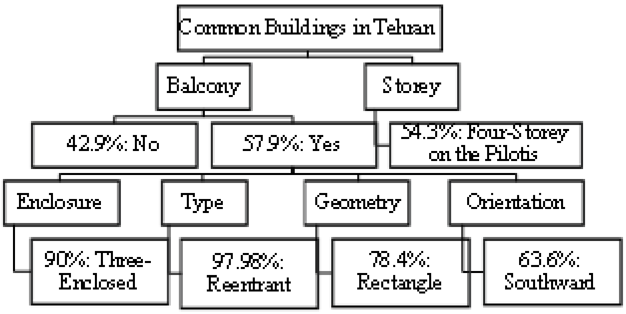

Fig. 1. The result of existing buildings in Tehran.

According to the results of examining the available samples in Tehran as well as the models used in various papers [51,62,63], a four-story building base model with dimensions of 18 meters in length, 7.5 meters in width and 15 meters in height, having three residential units at each story measuring 7.5*6*3m, each unit with a rectangular balcony southward with a length of 4.5 meters and a depth of 1.5m has been chosen. The windows of the balconies are aligned with the axis of each unit and a 1*2 m opening has been placed in the axis. The dimensions of the window on the opposite side are 1 * 1 m with 1meter high from the floor (Fig. 2).

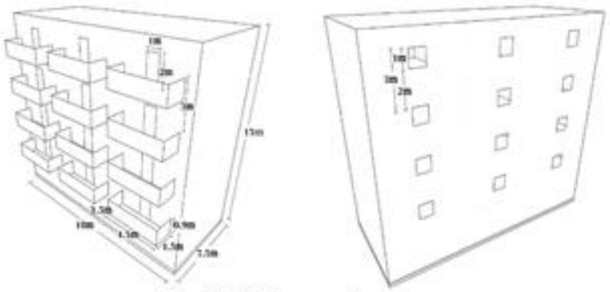

Fig. 2. The base mode

III. Simulations and Discussion of Results

A. *The result of the first-phase simulations*

• Step 1: Balcony orientations in the base model is simulated in four main directions: south, north, east and west, northeast, northwest, southeast, and southwest. According to the Fig. 3, the lowest energy consumption with 317.9 kwh per 1m^2 is allocated to the southward balcony and this orientation is selected for next simulations.

TABLE 1. The process of simulations

Simulation	Parameter analysed
Phase 1	Step1: geographical directions of balcony: eight geographical directions
	Step2: Geometry of balcony: rectangle, curved and trapezium)
	Step3: Enclosure of balcony: one-side(1), two-side including in west(2W) or east(2E) and three-side(3) enclosure
	Step4: Type of balcony: protrusive(P), reentrant(R)) and semi protrusive-semi reentrant(S)
	Step5: shading on the fourth floor: consistent with the conditions of the bottom floors balconies
	Step6: Partition type of balcony: solid(SP), with vertical(V) and horizontal(H) dividers
Phase 2	Step7: Alterations in the depth of the balcony.
	Atep8: Changes in the length of the balcony.
	Step9: Different solidarity ratio of balcony partition.
	Step10: Changes in depth, length and partition altogether.

• Step 2: The geometries of rectangular, curved, and trapezoidal balconies are simulated towards the south. According to Fig. 4 over the year, the rectangular balcony-model with 317.19 kwh per 1m^2, encounter a 0.32% and 0.6% reduction in the annual energy consumption in comparison with the curved and trapezoidal balcony-model respectively.

• Step 3: Different balcony enclosures are simulated, including one -side enclosed, two-sides enclosed (east and west edge) and three-sides enclosed. According to Fig. 5, the energy consumption in the model with west-enclosed balcony is lower than the other ones, having 316.8 kwh/m^2 annually.

• Step 4: Three simulations are accomplished respecting to this issue: re-entrant, protrusive and semi protrusive-semi re-entrant balcony. The energy consumption of the model with a protrusive balcony is much less than the other two models over the year, so that this difference is nearly half as much as the re-entrant balcony. The main reason for this difference is the decrease in ratio of the surface-to-volume in this model compared to the re-entrant balcony-model (Fig. 6).

• Step 5: The impact of the shading on the fourth floor is surveyed. The modelled shading is fully in compliance with the balcony's conditions. Based on the Fig. 7, the annual energy consumption in the model with fourth floor-shading is 317.6 kwh/m^2, while in the other model is 316.3 kwh/m^2.

• Step 6: Three models are analysed for the balcony partitions, including fully solid partition, vertical dividers and horizontal dividers. Fig. 8, shows the model containing vertical dividers has less annual energy consumption per square meter in the building, with 302.7 kwh/m^2, reducing 4.3% and 0.7% of energy consumption than solid partition and horizontal divider, respectively.

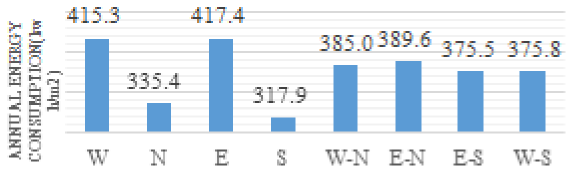

Fig. 3. The effect of balcony orientation on energy consumption.

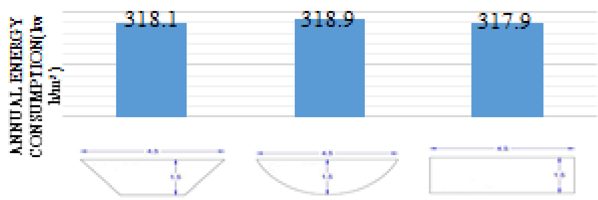

Fig. 4. The effect of balcony geometry on energy consumption.

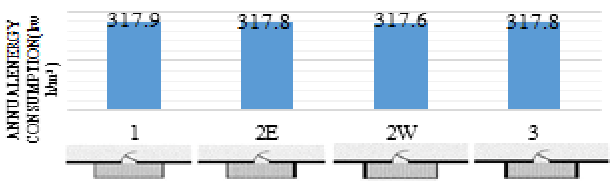

Fig. 5. The effect of balcony enclosure on energy consumption.

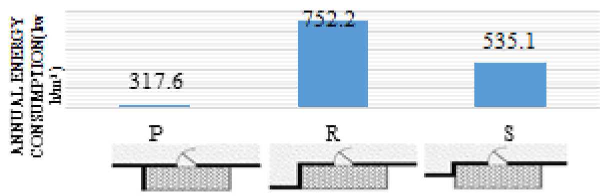

Fig. 6. The effect of balcony type on energy consumption.

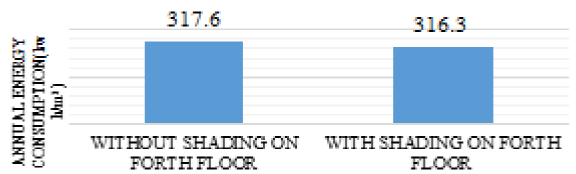

Fig. 7. The effect of forth floor-shading on energy consumption.

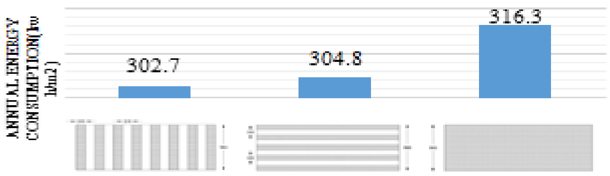

Fig. 8. The effect of partition type on energy consumption.

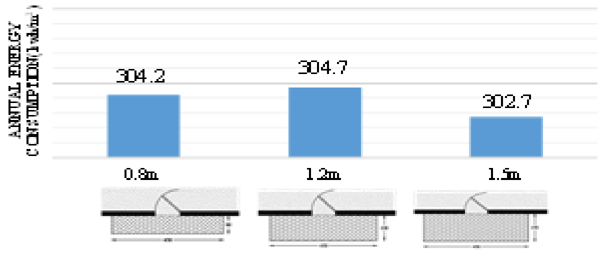

Fig. 9. The effect of depth of the balcony on energy consumption.

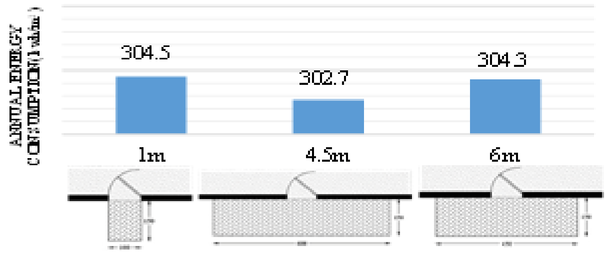

Fig.10. The effect of balcony length on energy consumption.

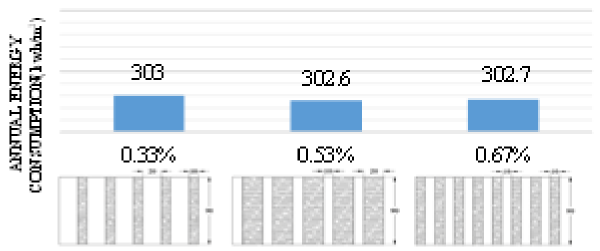

Fig. 11. The effect of solidarity of partition on energy consumption

B. Second-Phase Simulation

The model achieved in the first phase has a rectangular and protrusive balcony southward with west enclosure, accompanied by vertical dividers and the fourth floor-shading similar to balconies conditions. For the second phase, the parameters of the balcony (length, depth, and walls ratio) are altered first independently and then altogether, and their effects on the energy consumption are analysed. The results are listed as follows:

• Step 7: depth of balconies is altered in 0.8, 1.2 and 1.5 meters. According to Fig. 9, the building with 1.5m-depth balconies has a lower annual energy consumption per square meter.

• Step 8: The changes in the balcony's length are simulated including the length of 1 meter, 4.5m, and 6m.
According to Fig. 10 in the building, the best conditions among three models go to the 4.5m length balcony. This model has 0.61% and 0.54% reduction rather the model with 1m length, and 6m-long model.

• Step 9: The ratio of the balcony partition is changed. This value is the ratio of solidarity of the balcony Partition in terms of percentage. The variations are presented in three ways: the balcony partition with 20 cm thickness dividers in 10 cm intervals, 10 cm thickness dividers in 10 cm intervals and 10 cm thickness dividers with 20 cm intervals (67%, 53% and 33%). According to Fig. 11, the best consumption belongs to the partition model with ratio of 53%.

• Step 10: parameters of balcony (length, depth and partition ratio) have been altered altogether. As mentioned, three values are considered for each of them which totally include 27 simulations (TABLE 2). The result shows various dimensions and parameters of balcony do not make considerable change in energy consumption.

IV. CONCLUSION

In this paper, all the qualitative and quantitative parameters related to the balconies in several simulations were examined and their impacts on energy consumption were analysed (Fig. 12). These simulations were carried out in two phases. Orientation, geometry, enclosure and balcony types, the effect of the shading on the fourth floor and the type of balcony partition were simulated in the first phase. All the simulated dimensions, sizes and shapes are based on prevailing balconies, and building codes in Tehran. The purpose of this study is presenting the contributing factors in optimal design of the balcony and achieving its optimal pattern in order to reduce energy consumption. With the obtained analysis from the simulations in the first phase, it was found out that in terms of directions, the southern balcony had the best performance with up to 23% decrease in annual energy consumption. It can be stated that geometry, enclosure, the shading on the fourth floor and partition type had a small impact on annual energy consumption. In the case of the balcony type, the re-entrant balcony had the worst performance in energy consumption and the protrusive balcony had the best performance, decreasing this value by approximately 60%.

TABLE 2. Simulated different balcony parameters and the results.

Model number	Length (m)	Depth (m)	Solidarity ratio	Energy consumption (kwh/m2)
1	1	0.8	0.30	304.6
2	1	0.8	0.50	304.8
3	1	0.8	0.60	305.6
4	1	1.2	0.30	304.7
5	1	1.2	0.50	305.6
6	1	1.2	0.60	304.2
7	1	1.5	0.30	305
8	1	1.5	0.50	304.5
9	1	1.5	0.60	304.1
10	4.5	0.8	0.30	304.4
11	4.5	0.8	0.50	304.2
12	4.5	0.8	0.60	305.5
13	4.5	1.2	0.30	304.9
14	4.5	1.2	0.50	304.7
15	4.5	1.2	0.60	304.6
16	4.5	1.5	0.30	304.3
17	4.5	1.5	0.50	303.8
18	4.5	1.5	0.60	303.6
19	6	0.8	0.30	304
20	6	0.8	0.50	303.9
21	6	0.8	0.60	304.5
22	6	1.2	0.30	303.4
23	6	1.2	0.50	304.1
24	6	1.2	0.60	304
25	6	1.5	0.30	305

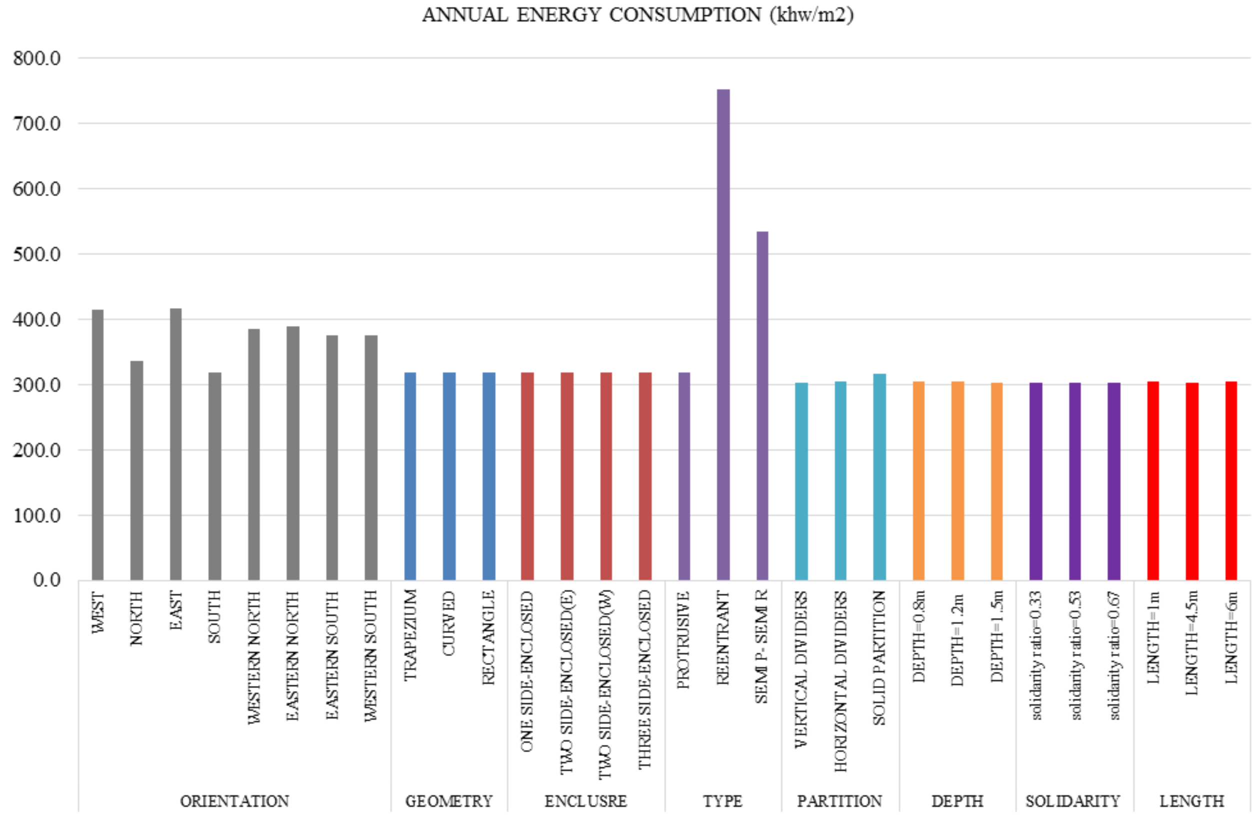

Fig. 12. Comparison of balcony parameters impact on annual energy consumption.

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Elahe Mirabi, Department of architecture, Ilam University, Ilam, Iran, 09383476758.

Nazanin Nasrollahi, Department of architecture, Ilam University, Ilam, Iran, 09383476758